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ELECTRIC SMELTING OF IRON ORES FOR LESS DEVELOPED AREAS

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1. INTRODUCTION

The dominating position of iron amongst metals has found expression in technical terminology: We talk about "ferrous" in contrast to "non-ferrous" metallurgy.

Production statistics also indicate that we still live in "The Iron Age". The world's annual production of pig iron is approximately 250 mill. tons, while the production of aluminium, copper and zinc is in the order of 5 mill. tons a year each - i.e. 2% of the iron production.

All the big industrial countries have well established iron and steel industry. It might be said that the status of iron metallurgy in a country expresses its industrial potential.

The traditional furnace type for production of liquid pig iron from ore is the blast furnace. Already before the last World War blast furnaces were developed to very large units and adopted by the larger steel works around the world.

Important progress in the blast furnace operation has been achieved by means of pretreatment of the raw materials in the sinter works. In U.S. and Europe, as well as in Japan, the capacity for sintering ore fines and concentrates has been increased. Based on pioneer work at Domnarvet in Sweden, many blast furnace plants are producing a self-fluxing sinter, i.e. sintered iron ore, including the fluxes. This type of sinter reduces the carbon as well as the energy requirement in iron ore smelting both in the blast furnace and in the electric furnace.

The average capacity of the 266 blast furnaces in operation in U.S.A. per January 1st, 1959, was 960 tons. In Western Germany 127 blast furnaces were in operation in 1961 - average daily production 550 tons. Approximately 1000 tons per 24 hours appears to be a typical production capacity for new blast furnaces. Recently, three integrated iron and steel works have been erected in India, each with a capacity of approximately 1 mill. tons of steel per year. All these works are equipped with blast furnaces designed for a production of approximately 1000 metric tons per day.

There are a few very big blast furnaces with a production capacity of up to 2000 tons.

Large production units facilitate mechanization of the handling of raw materials, etc. and contribute to a reduction of the number of labour hours per ton of pig iron. For the very large blast furnaces the labour requirement is only a fraction of one hour per ton.

Despite the impressive size and efficiency of the blast furnace, this type of pig iron production unit has met with considerable criticism over the last decade. Extensive research and development work has been carried out to investigate alternative methods for obtaining iron from iron ores. One of the main reasons for these efforts has been the fact that the large blast furnaces establish very strict specifications for the size and mechanical strength of the coke.

Coal suitable for the production of high quality coke is required. These good coking coals are not available everywhere, even in countries with extensive coal resources.

2. OFF-GRADE COAL

The electric pig iron process was originally based on the use of a mixture of lumpy coke and coke breeze. A majority of the plants are using gas works coke, but in some cases a mixture of coke and anthracite is being used. The electric pig iron process is now developed for the use of raw coal such as baking coal, non-coking coal, lignite, etc. The volatiles in the coal are utilized in the process for preheating of the charge and prereduction of the ore.

There are also ores which cannot be smelted in blast furnaces - the so-called titaniferrous iron ores containing about 10% TiO_2 which gives operational trouble with deposits of titanium-carbides and - nitrides in the blast furnace shaft.

The electric smelting of TiO_2-containing iron ores was first developed in Norway and later in Japan. The expansion of electric pig iron smelting in Japan is based on the use of one of the very few domestic resources of iron ore, the beach sand concentrates. This sand is concentrated magnetically to 55 - 60% Fe and 8 - 12% TiO_2, sintered and smelted in electric pig iron furnaces.

Low-grade iron ores which are not amenable to ore-dressing and concentration are uneconomical to smelt in blast furnaces due to the unreasonably high coke consumption. In many of the industrially less developed areas a situation prevails where one or more of the basic factors required for the blast furnace process are missing. Iron ore of the type suitable for blast furnace burden will have to be imported from abroad, or transported over long distance, or only low-grade coal, non-coking coal, lignite or brown-coal are available. In quite a few of the new steel countries electric pig iron smelting has been adopted and solved the problems of pig iron production from raw materials unsuitable for the blast furnace.

3. DESIGN FEATURES OF ELECTRIC PIG IRON FURNACES

Figure I gives a vertical cross section through an ELKEM pig iron plant. The charge is distributed to the furnace bins by transport with skip-hoist and telpher bucket. From the bins above the electric furnace the charge flows by gravity through the chutes to charge openings in the roof, and keeps the electric furnace automatically filled with charge.

All the furnaces which have been built by Elektrokemisk during the last ten years are equipped with circular furnace pots and three Søderberg electrodes arranged in delta formation. Below each electrode considerable quantities of coke float in the slag, the so-called coke bed, which constitutes an important element in the smelting process. The electrode current passes from the electrodes through the preheated part of the charge, which is conductive to electricity, and then through the coke bed and the slag. The main reaction as well as the fusion of the charge takes place in the vicinity of the electrode tips where the liberation of electric energy is most extensive. As the height of the charge above the smelting zone is relatively low and the quantity of gas is considerably smaller than in blast furnaces because no air is blown in, relatively little preheating and CO reduction take place in the electric furnace, except with a specially prepared, porous charge.

As for blast furnaces, iron and slag are tapped from a tap hole near the furnace hearth. Reaction gases are sucked off from openings in the furnace roof,

scrubbed with water and distributed to gas holders and the gas distribution system.

The pioneer furnace for closed operation with collection of unburnt CO-gas was developed by the Norwegian engineers Tysland and Hole at Christiania Spigerverk at the outskirts of Oslo. This furnace was in operation from 1923 to 1947 under inspiring leadership of Mr. Gunnar Schjelderup. Table 1 presents a list of electric furnaces of Tysland-Hole - ELKEM type in operation or presently under construction.

The total furnace capacity installed and ordered per September 1st is abt. 775 MW.

In this table are not included furnaces for abt. 150 MW built by other furnace manufacturers. In addition also comes a number of small furnaces built after the war in Japan.

4. ELECTRIC PIG IRON SMELTING TO-DAY.

Only a short description will be given here of the latest electric pig iron furnace installations.

Christiania Spigerverk acquired a smelting plant at Bremanger in Western Norway in 1952. Here a 33 MVA electric furnace and a new sintering plant was installed in 1959. This furnace is in production on a special grade titanium and vanadium bearing pig iron.

An important and courageous step was taken by A/S Norsk Jernverk just after the war, in their decision to instal three electric pig iron furnaces, later supplemented with a fourth furnace unit, each with 33 MVA transformers. This state-owned plant in Mo i Rana, just below the Polar Circle, has been in continuous operation since 1955. The yearly production is now abt. 360.000 metric tons, partly for the company's own steel works and partly for sale.

Typical data for the present operations are as follows:

Furnace load	20.000 - 25.000 kW
Power consumption for pig iron with 1% Si	Abt. 2000 kWh per metric ton
Coke consumption (85% Fixed C), dry basis	350 - 400 kgs
Electrode paste	5 - 10 kgs
Down-time	2 - 5 %
Labour man-hours per ton	1.0 - 1.5

Presently the plant is being expanded with two 50 MVA ELKEM furnace units scheduled for completion towards the end of 1963. It is expected that the total annual capacity of the six furnaces will then reach 700 - 750.000 tons.

At Matanzas in Venezuela the large integrated iron and steel plant planned and built by Innocenti, Milan, was started up in 1961. Here nine 33 MVA ELKEM units are being put into operation. This state-owned enterprise is founded on the famous Cerro Bolivar "Iron Mountain", said to be the world's richest iron ore body so far discovered.

Other recent additions to the furnace family are two 18 MVA furnaces for Israel Steel Mills, and a 13.2 MVA furnace which Elektrokemisk A/S have designed for the Consolidated Mining and Smelting Company of Canada Ltd., in Kimberley, British Columbia.

Early 1962 an 18 MVA ELKEM furnace for the smelting of sintered beach sand concentrate was started up by Nisso Steel Mfg. Co. Ltd., Hachinohe, Japan.

5. PREPARATION OF RAW MATERIALS

As in the blast furnace operation progress has been made in raw materials preparation also for electric pig iron smelting. Also for electric furnace smelting the lump sizes of the charge components and the content of fines and dust are important for the furnace performance. Careful control with lump size and elimination of fines by screening are now standard practice with all larger electrothermic plants.

Systematic control of lump size has improved charge porosity and gas distribution. This provides a wider reaction and smelting zone in the electric furnace as well as smoother descent of the charge. Self-fluxing sinter eliminates calcination of raw limestone and dolomite by electric power. Apparently the self-fluxing sinter has increased chemical reactivity which is reflected in higher CO_2 content in the furnace gas. Also the self-fluxing sinter is supposed to lower the formation temperature of the slag in the furnace, whereby reduced temperature in the reaction zone has been established.

6. PREREDUCTION

In addition to the physical charge preparation by screening and agglomeration, the electric pig iron process is even more drastically improved by thermal and chemical pretreatment. Hereby a new process step has to be adopted - prereduction. Prereduction may be introduced in addition to sintering, or combined with agglomeration.

Different research institutes and private companies have attempted to develop prereduction. Independent groups in U.S.A. and Canada, and also groups in Japan, have worked intensively for improving the electric iron ore reduction. The object has been to make the process competetive with the conventional blast furnace in areas mainly supplied with thermal power. Comprehensive tests have been made with the Strategic-Udy process using a rotary kiln for preheating and prereduction, followed by electric smelting with a special technique. This process is based on the late dr. Marwin Udy's inventions. The Udy process facilitates selective reduction of complex ores and allows the use of fine-grained charge. Further, the process is well suited for direct production of semi-steel with medium or low carbon content.

Independently, Elektrokemisk, have undertaken research and development work on preheating and prereduction, and a summary of the methods used and some results obtained will be given here.

7. SHAFT PREHEATING

The simplest way to improve the performance is to preheat the complete charge in shafts installed directly above the electric furnace. In Elektrokemisk's Research Station, at their ferro-alloy smelter at Fiskaa Verk near Kristiansand in South Norway, a number of pilot plant shafts and a commercial-size prototype shaft have been built. A pilot shaft for a capacity of 500 to 1000 kgs of charge per hour is

erected directly above an electric furnace. Here the complete charge is heated counter-currently in a stream of hot combustion gases. Fuel oil or CO gas from the electric furnace is burnt with a controlled quantity of air and the hot gases are passed through a bed of charge in the shaft.

A considerable number of tests has been made with different iron ore and sinter charge. Reduced power consumption and increased production are obtained, not only due to the sensible heat in the charge, but also due to more indirect reduction. (exothermal formation of CO_2 by gas reduction), in the electric furnace:

Table 2.

Ore	% Fe	Cold charge			Hot charge		
		% CO_2	kgs Fixed C per metric ton	kWh per metric ton	% CO_2	kgs Fixed C per metric ton	kWh per metric ton
Magnetite Lump Ore	56	9	295	2350	23	84	1800
Self-fluxing sinter	54	14	308	2080	41	286	1580

8. ORE/CARBON PELLETS

Iron ores quite frequently are available as fines or as concentrates from ore dressing plants, while raw coal fines represent the cheapest source of carbon. These raw materials can be agglomerated together to produce charge briquettes or pellets for electric smelting.

Elektrokemisk's Research Division has during the last five years, conducted comprehensive tests with agglomeration, prereduction and smelting of charge pellets.

The preferred method is to pelletize ground ore and coking type coal with a binder. The pellets are produced on an inclined rotating disc, and the raw, soft pellets hardened by storage or drying. The hardened pellets are sufficiently strong for transport and handling within the plant limits. The charge pellets with addition of correction materials are heated counter-currently in a shaft by a stream of hot gases. Hereby the pellets are baked hard by carbonization of the coal, forming a strong carbon bond in the hot pellets. The hydro-carbons and hydrogen in the coal are distilled, and 10 - 30 % of the oxygen in the iron ore is removed in the shaft. The red-hot, prereduced pellets are continuously discharged and fed directly to the electric furnace below.

Due to the intimate contact between ore and coal in the pellets, and the content of volatiles in the coal, prereduction is obtained at temperatures far below the fusion point of the pellets. The charge pellets make a porous, reactive charge with excellent smelting properties. The favourable chemical reactivity is reflected in the high CO_2 content in the electric furnace reaction gas. This indicates a high proportion of indirect reduction - as in the blast furnace. In the Fiskaa pilot plant Elektrokemisk have operated test runs on ore/carbon pellets with magnetite as well as hematite iron ore, the following results being obtained:

Table 3.

Iron Ore	% Fe	Coal	% Fixed C	% CO_2	kgs Fixed C (per metric ton of pig iron)	kWh (per metric ton of pig iron)
Syd-Varanger	64	Longyear	50	30	290	1350
Algerie	56	Pocahontas	74	41	260	1270

In conventional pig iron plants concentrates are agglomerated by sintering in a separate, expensive plant where the ore is heated to incipient fusion and thereafter cooled for screening and transportation. In the new ELKEM process the pelletized charge is baked and prereduced simultaneously in simple shafts directly above the electric furnace which received the hot, partly reduced pellets. This new technique simplifies the agglomeration plant by combined agglomeration, preheating and prereduction. Hereby the charge is conditioned for the electric furnace smelting with considerably reduced power consumption and higher pig iron production.

9. ROTARY KILN

A mixture of iron ore, limestone and coke (or raw coal) is heated to about 1000°C in rotary kiln, whereby reactions between iron oxides and carbon is started, without fusion of the charge. The kiln product is transferred hot to the electric furnace in insulated containers.

The prereduction kiln is of the same type as used in other industries, for instance for burning of Portland cement clinker. These kilns are mechanically strong and have a long life. By placing thermo-couples through the kiln lining the temperature may be accurately controlled, so as to make sure that the working temperature is below the softening point of the charge. Thereby the cumbersome formation of rings is avoided. CO gas produced from reaction between iron oxides and carbon in the charge is burnt above the charge bed in the kiln by air supplied in controlled quantities through ports in the kiln shell. This supplies heat for the iron ore reduction.

Raw coal is a preferred reducing agent for kiln prereduction. By feeding raw coal through special scoop feeders directly through the kiln shell, an instantaneous carbonization of coal takes place due to the contact between the coal and the hot charge in the kiln. Hereby ring formation on the kiln lining is avoided even with strongly caking coals. This type of coal charging sideways into the kiln liberates volatiles from the coal which burns with oxygen in the kiln and supplies additional heat of combustion for the prereduction and preheating of the charge. Many types of raw coal produce char of high chemical reactivity, advantageous for high rate of reduction in the kiln.

By combustion of all CO gas formed in the kiln and electric furnace as well as volatiles from the coal, 50% or more of the oxygen in the ore may be removed by prereduction in the kiln. Preheating and prereduction decreases power consumption drastically with corresponding increase in the iron production. In Fiskaa's pilot plant test with high-grade ore from Algerie and Labrador, power consumption figures in the range of 900 - 1300 kWh have been obtained. With low-grade silicious ore, power consumptions in the range 1500 - 1800 kWh are typical.

For industrial use of the combination rotary kiln/electric furnace, the kiln would have to be placed on unreasonably high foundations if the hot charge should be transferred directly to the electric furnace charge openings.

The practical arrangement on a large scale, therefore, is to place the rotary kilns on normal foundations at ground level, discharge the hot prereduced material into a surge bin and transport in insulated containers to the electric furnace feed bins.

10. NEW INDUSTRIAL INSTALLATIONS

Preheating in rotary kiln with transfer of hot feed has already been in operation since 1958 in four 13.5 MVA ferronickel furnaces belonging to S.A. Le Nickel at their New Caledonia plant. A description of the plant and operation in New Caledonia has been published in Journal of Metals, March 1960.

The smelting technique adopted in this large plant, which now consists of five electric furnace units, originates from three smelting test campaigns at Elektrokemisk's Research Station.

An additional ferronickel furnace will soon be started up in Brazil by Morro do Nickel S.A.

In the pig iron field Rudnici I Zelezara SKOPJE in Jugoslavia will instal seven 34.5 MVA ELKEM furnaces, each with a rotary kiln. Here a low-grade chamosite ore, limestone and raw lignite coal will be heated in F.L. Smidth rotary kilns with scoops for feeding the lignite directly through the kiln shell. Despite the very low grade of the ore, the CO gas produced in the kilns and electric furnace and hydro-carbons and other volatiles from the lignite coal will cover the heat requirements for drying and heating of the charge in the kilns as well as partial reduction of ore and calcination of limestone.

Sinai Manganese Corporation have recently ordered a rotary kiln and 13.2 MVA ELKEM electric furnace for extraction of pig iron and ferromanganese from low-grade iron manganese ore in Egypt.

In Portugal a 13.2 MVA ELKEM pig iron furnace installed five years ago for conventional pig iron smelting is now being rebuilt for shaft prereduction of ore/carbon pellets. Presumably this plant will be in operation within the end of 1962.

In Venezuela, Corporacion Venezolana de Guayana will try the Strategic-Udy process on furnace No. 9. The furnace plant is now being equipped with a rotary kiln and the electric furnace adopted for the process in cooperation with Stratmat Ltd., Koppers Inc. and Elektrokemisk.

11. FUTURE TRENDS

Electric pig iron smelting is a special iron ore reduction process used and under installation in seventeen different countries. The electric furnaces are used not only in small iron works, but also in integrated iron and steel works of intermediate size with 300.000 - 700.000 tons annual capacity. The obvious fields for electric smelting of iron ore are areas in the world where coking coal of suitable quality for production of metallurgical quality coke is not available, while electric power such as water-power or cheap thermal power is at disposal.

The electrical smelting process has undergone refinement and technical advances in the last few years. The original conception of electric smelting was to supply the thermal requirements of the process from electrical energy and the chemical requirements from carbonaceous material. The present trend is to substitute carbonaceous material or other fuels for a portion of the thermal

requirements previously supplied entirely by electricity. This procedure has been a natural development. As the demand for larger and larger electric reduction units developed, the size of the furnaces grew almost in direct proportion. As the electrical load per furnace increased, the complexity, cost and power demand of the electrical systems continued to increase.

To reduce the electrical thermal load and lessen power consumption, operating procedures were modified to pretreat the raw materials, by preheating and/or partially prereducing, before charging them into the smelting furnace.

By reduction of the power consumption and increase in furnace unit capacity, the pig iron process may gradually achieve a more important part of the new pig iron production capacity, perhaps mainly by expansion to countries and areas which have not so far developed steel industry.

The great tolerance of the electric furnace with regard to quality of iron ores and reducing agents will justify electric smelting for new pig iron plants. Each project has to be examined very carefully with testing of the raw materials concerned to find the cheapest solution with regard to installation and operating costs.

Table 1.

	Number of furnaces in operation	MW	Number of furnaces under construction	MW	Total number of furnaces	Total MW
Canada	1	10.0			1	10.0
Egypt			1	10.0	1	10.0
Finland	1	10.0			1	10.0
India	2	20.0			2	20.0
Israel	1	14.5	1	14.5	2	29.0
Italy	5	42.0			5	42.0
Japan	2	19.5			2	19.5
Norway	5	110.0			5	110.0
Peru	2	20.0			2	20.0
Philippines			2	29.0	2	29.0
Portugal	1	10.0			1	10.0
Spain			1	6.5	1	6.5
Sweden	4	40.0			4	40.0
Switzerland	1	8.5			1	8.5
Venezuela	4	88.0	5	110.0	9	198.0
Yugoslavia	3	30.0	7	182.0	10	212.0
	32	422.5	17	352.0	49	774.5

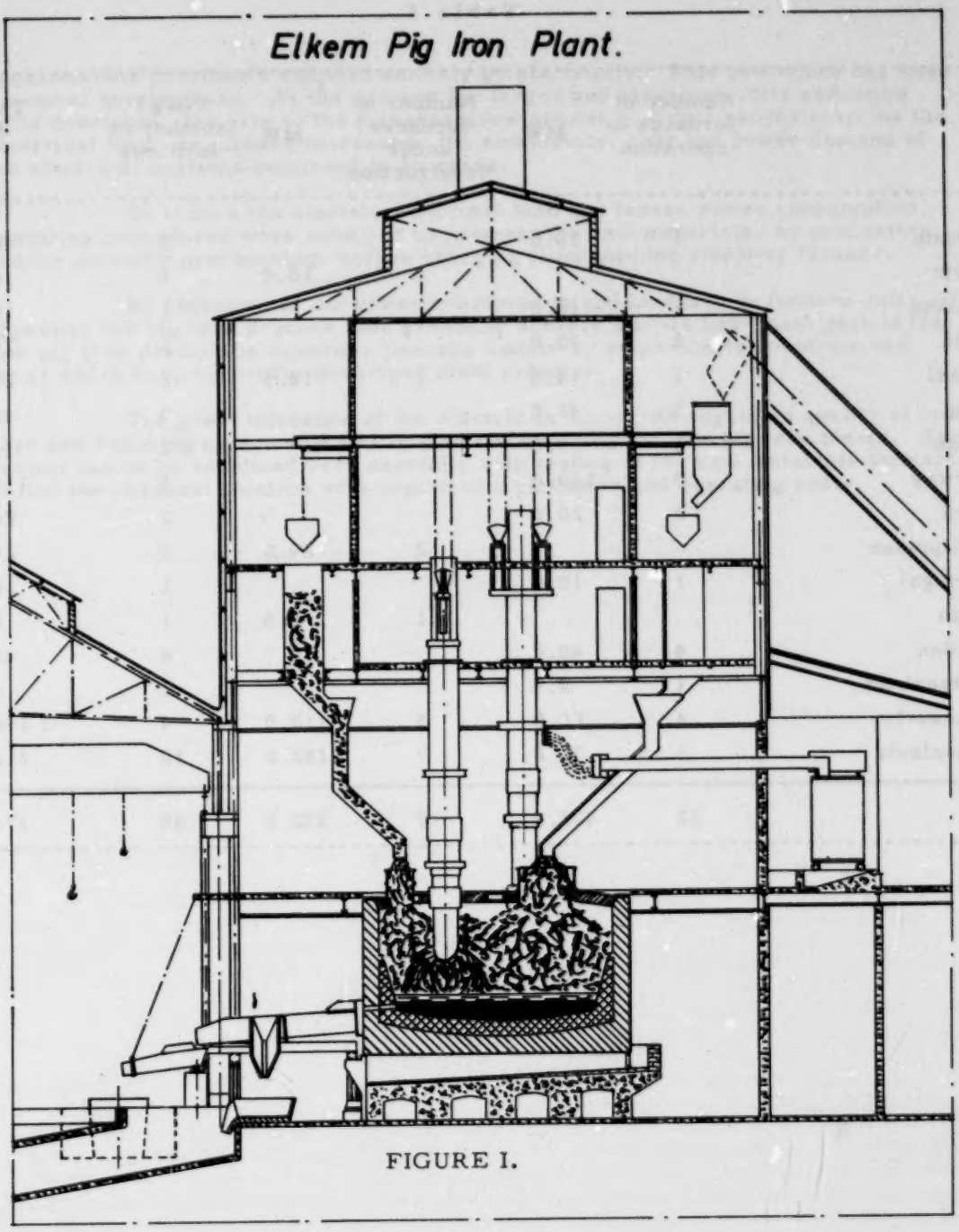

FIGURE I.

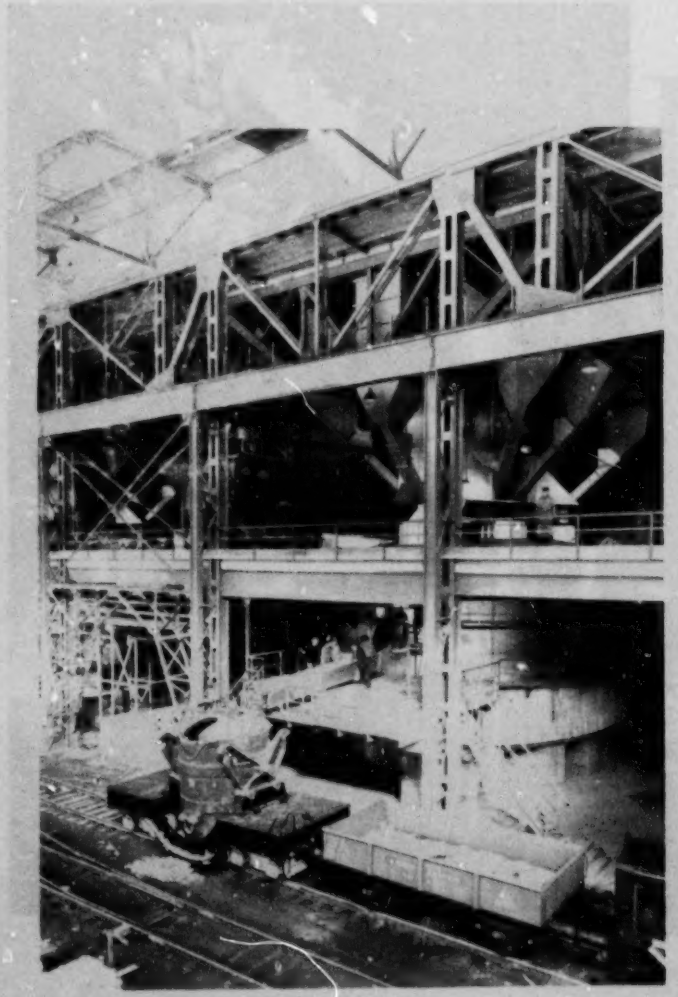

Fig.2 - From Norsk Jernverk, Mo i Rana, Norway

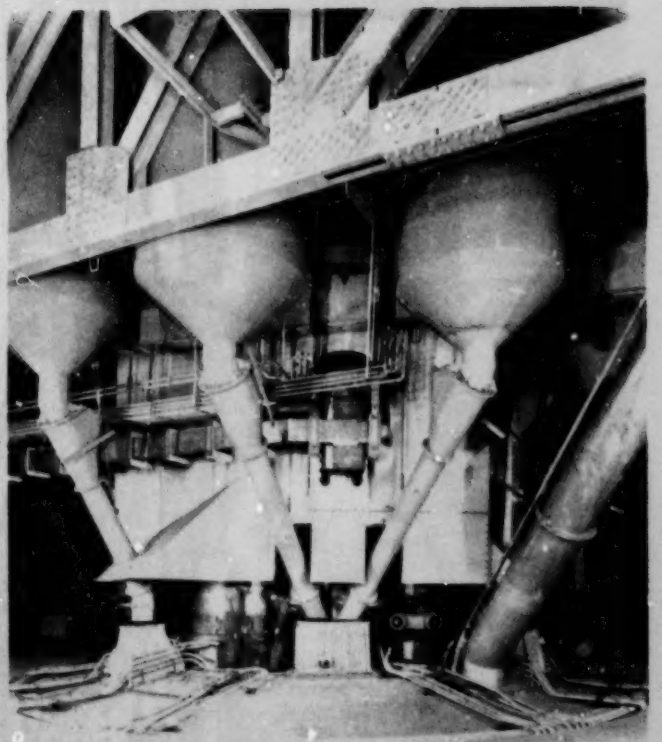

Fig.1 - From Bremanger Smelteverk, Svelgen, Norway

Fig.3 - From Corporacion Venezolana de Guayana, Matanzas

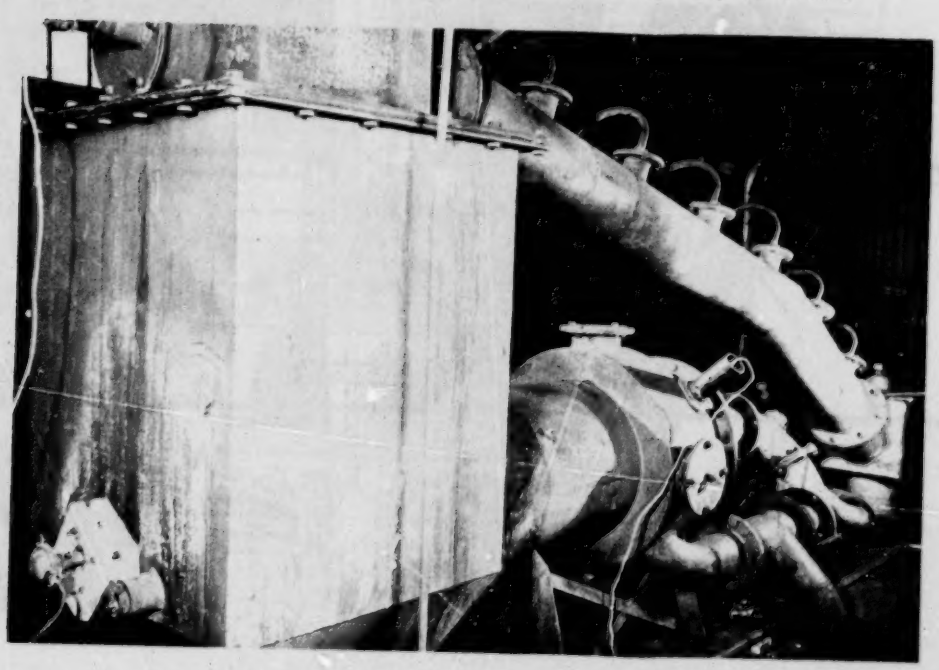

Fig.4 - Pilot Preheating Shaft, Elektrokemisk A/S, Fiskaa Verk, Norway

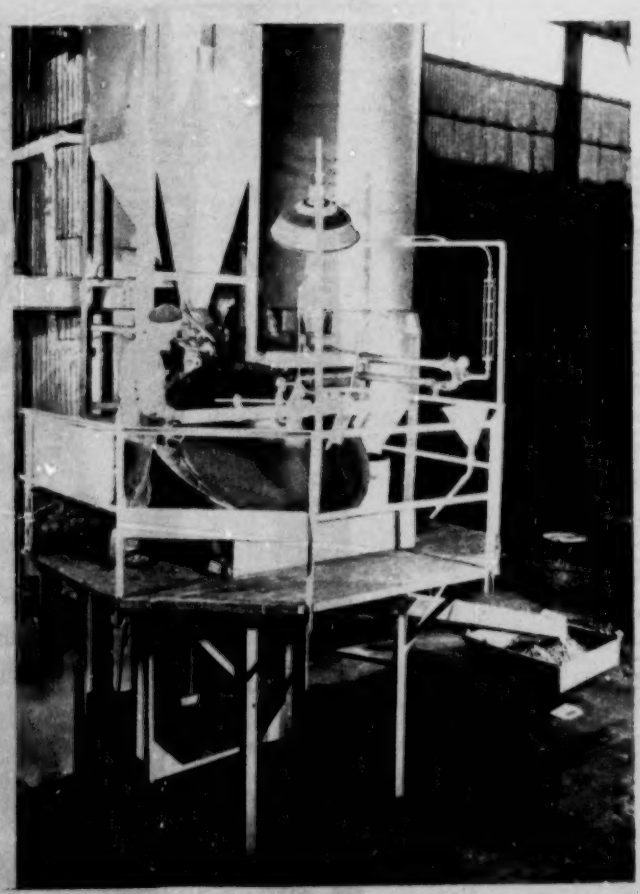

Fig.6 - Pelletizing Plant at Fiskaa Verk

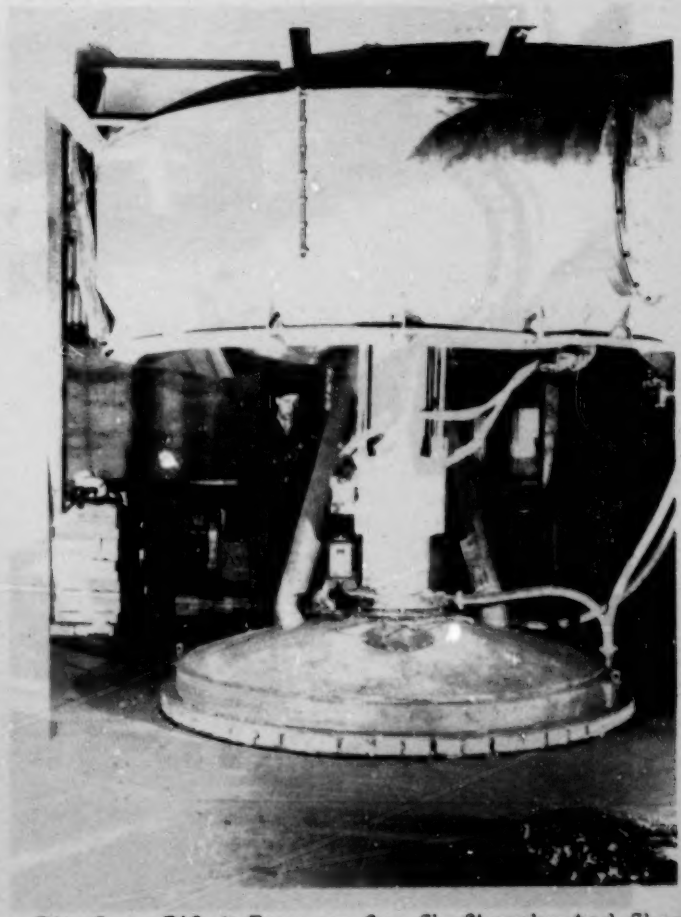

Fig.5 - Pilot Furnace for Shaftpreheated Charge

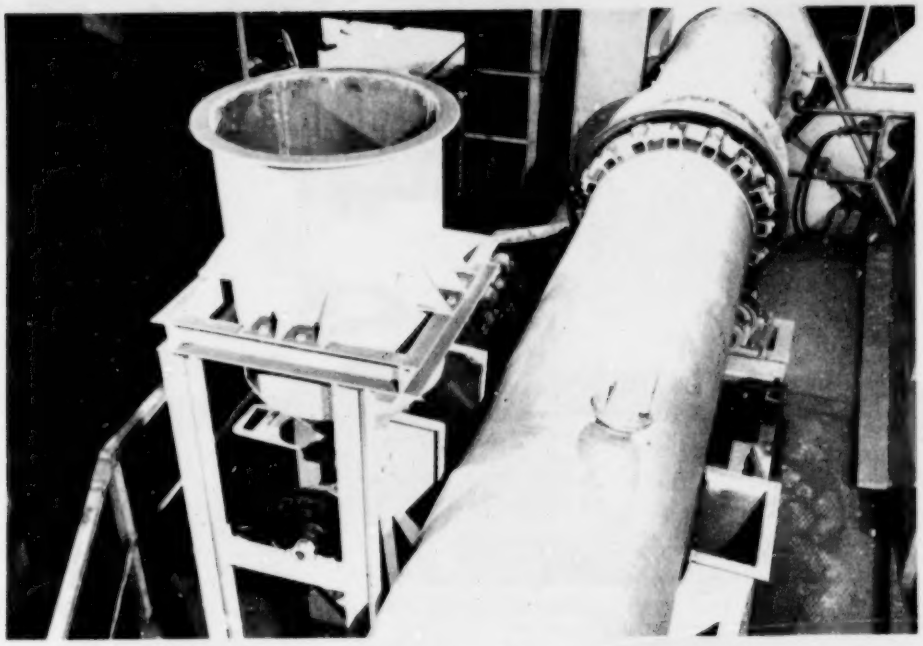

Fig.7 - Pilot Rotary Kiln, Fiskaa Verk

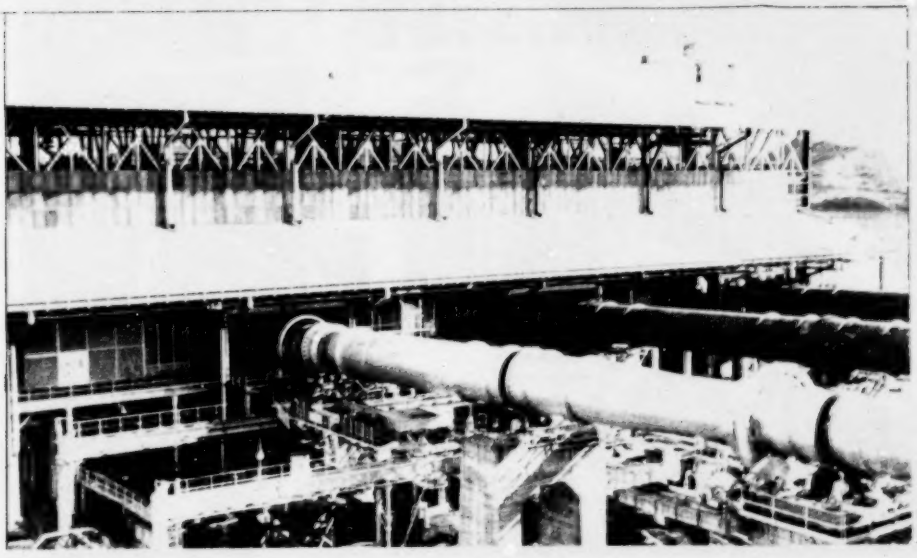

Fig.8 - From Ferronickel Plant in New Caledonia

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